PCT/IL 99 / 00495

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מספר: Number	126168
תאריך: Date	10-09-1998
הוקדם/נדחה Ante/Post-dates	

חוק הפטנטים, התשכ"ז -- 1967
PATENTS LAW, 5727-1967

בקשה לפטנט
Application for Patent

C:30930

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מבקשת פטנט from Application	*לבקשה/לפטנט to Patent/Appl.	מספר/סימן Number/Mark	תאריך Date	מדינת האיגוד Convention Country
No. ________ .מס dated ________ מיום	No. ________ .מס dated ________ מיום			

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METHODS AND APPARATUS FOR ODOR REPRODUCTION

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METHODS AND APPARATUS FOR ODOR REPRODUCTION

FIELD OF THE INVENTION

The present invention relates generally to apparatus and methods for generation, emission, transmission, reproduction and memory storage of fragrances, scents, odors and smells.

BACKGROUND OF THE INVENTION

Apparatus and methods for sensing odors are well known in the art. For example, sensing, identifying or categorizing a particular odor may be accomplished by means of gas chromatography devices and mass spectrometers which chemically analyze an odor, and electronic or artificial "noses" which provide a characterizing signature of the odor.

Odor output devices for delivery of fragrances to a user's nose are also well known. For example, a fragrance output device used in conjunction with virtual reality systems is described in US Patent 5,591,409 to Watkins. US Patent 5,724,256 to Lee et al. describes a fragrance mixing device which can be used in multimedia systems.

Systems which attempt to link odor sensing devices with odor delivery devices are known in the prior art. For example, "Transmission of Olfactory Information for Telemedicine", Keller *et al.*, Interactive Technology and the New Paradigm for Healthcare, K. Morgan *et al.*, eds., IOS Press and Ohmsha, Amsterdam, 1995, chapter 27, pp. 168-172, contemplates sensing known, predetermined odors with sensing devices, transmitting odor information related to the known odors to an odor output device, and using the output device to replicate the known input odor. It is important to note that this reference and the above cited fragrance mixing devices of the art strive to attain an *exact* reproduction of a *predetermined* input odor.

In color television or color photography, it is known how to reproduce arbitrary colors by mixing basic colors, such as red, green and blue (RGB) or other primary colors, to reproduce faithfully or near-faithfully as possible, primarily all colors. Accordingly, there have been whimsical and April-Fool's-Day essays about an odor-version of RGB. For example, in May 1998 there appeared on the Internet a website with the domain name www.vol.it/sbdi/44/sbdi44it.htm, which described an odor system having 7 basic "RGB" odors - camphor, moss, flowers, mint, ether, putrid odor, and pungent odor. It is noted that this allegation was already raised in the 1960's, but has been long since recognized in the art to be erroneous. Another joke of note is "The New World Odor" from the WebWhackoWeekly of April 2, 1997.

However, despite such published farces, the prior art does not currently know of any basic odors which are analogous to basic colors.

In summary, it is clear that the prior art does not seriously address a fundamental problem of odor transmission: how to communicate and reproduce an arbitrary odor which is not predetermined or previously known.

SUMMARY OF THE INVENTION

The present invention seeks to provide methods for instructing an odorant-mixing output device to mix building-block odorants in the correct amounts and proportions so as to translate any odor input, even an unknown odor, into an odor output which faithfully reproduces the input odor.

It is noted that throughout the specification and claims the terms fragrances, aromas, flavors, scents, odors and smells, and any derivatives thereof, are used interchangeably. The term "odorant" denotes a substance which contributes to an emission of an odor by an odor output device. The odorant does not necessarily give off an odor, but may catalyze emission of an odor. The odorant may be a pure substance or a mixture of substances.

In a preferred embodiment of the present invention, an odorant concentration vector generator receives odor information, called an odor input vector, regarding an arbitrary input odor r sensed by an odor sensor. The arbitrary input odor is not necessarily predetermined or previously known. The odorant concentration vector generator computes a concentration vector which is employed to instruct an odor output device how to mix odorants in suitable proportions and concentrations to create a composite output odor which approximates the input odor. The odor output device has an odorant palette containing a multiplicity of predetermined odorants each having a predetermined odor signature. The odorants are predefined in terms of the same kind of odor vectors used to characterize odor r, thereby creating a matrix of odor vectors which characterize the odorants of the palette. This matrix multiplied by the concentration vector creates an output odor vector which characterizes an output odor r' which approximates the input odor r. The output odor r' is thus a combination of different concentrations of odorants, the concentrations being defined by the concentration vector.

The output odor r' is not necessarily an exact duplication of the input odor r. Specifically, the difference in odor between input odor r and output odor r' as perceived by a sufficiently representative human population is called a tolerance δ. The present invention provides

methods for minimizing tolerance δ such that the sufficiently representative human population perceives the output odor r' as an adequate substitute for input odor r.

The following is an illustrative example of the type of odor transmission possible with the present invention and not possible with the prior art. A movie director would like to add fragrances to scenes in a plurality of movies. In the prior art, the director must decide ahead of time which odors are to be transmitted. As mentioned in the background of the invention, the director must then provide all the end-users with the odorants needed to reproduce all of the known odors. If it is desired to transmit 1000 odors, then the director must either provide 1000 odorants which emit the exact same odors or somehow figure out how to mix the proper proportions of a smaller amount of basic odorants in order to reproduce the 1000 odors. In the prior art, the director has no way of knowing if 50, 600 or 999 basic odors are needed to reproduce the 1000 given odors and no way of knowing what the proper proportions are, without a lot of time-consuming, laborious and expensive testing.

In contrast, the director can use the methods and teachings of the present invention to know if 1000 basic odorants are really needed or if 49 are sufficient, and to know what proportions of which odorants to mix to achieve the desired output odors, without time-consuming and laborious trial-and-error. Much more importantly, the director is not limited to known input odors. Rather unknown odors, such as that provided by surprise or improvisation, can also be transmitted and faithfully mimicked with the methods of the present invention.

There is thus provided in accordance with a preferred embodiment of the present invention an odorant concentration system including an odor vector generator providing an odor vector representing an arbitrary odor, an odorant concentration vector generator receiving the odor vector and producing an odorant concentration vector.

There is also provided in accordance with a preferred embodiment of the present invention a system for reproducing odors including an odor sensor providing a sensed odor input vector representing an arbitrary odor sensed thereby, an odor output device, having a palette containing a multiplicity of predetermined odorants each having a predetermined odor signature, the odor output device providing a composite odor in response to an odorant concentration vector, and an odorant concentration vector generator receiving the sensed odor input vector and utilizing the predetermined odor signatures to produce the odorant concentration vector.

In accordance with a preferred embodiment of the present invention the odorant concentration vector generator includes a sensed odor input vector normalizer which modifies the sensed odor input vector such that the output of the sensor is normalized, whereby odors which are similar as perceived by a human are represented by modified odor input vectors which are close.

Further in accordance with a preferred embodiment of the present invention the odorant concentration vector generator normalizes the predetermined odor signatures to the output of the human nose.

Still further in accordance with a preferred embodiment of the present invention the modified odor input vectors which are close, are close according to at least one of the following metrics Euclidean distance, over-threshold Euclidean distance, over-threshold average difference, and maxima distance.

Additionally in accordance with a preferred embodiment of the present invention the odorants of the palette are predefined in terms of the sensed odor input vectors, wherein the palette includes q odors which are defined by a matrix M of q odor vectors $(\omega_{1,1}, \omega_{1,2}, \ldots \omega_{1,n})$, $(\omega_{2,1}, \omega_{2,2}, \ldots \omega_{2,n})$, ... $(\omega_{q,1}, \omega_{q,2}, \ldots \omega_{q,n})$.

In accordance with a preferred embodiment of the present invention the concentration vector generator generates a concentration vector b which instructs the palette how to mix the q odorants in order to create an output odor r' which mimics an input odor r, wherein the matrix M multiplied by the concentration vector b creates an odor vector $\omega' = (\omega'_1, \omega'_2, \ldots \omega'_n)$ and the concentration vector generator chooses the concentration vector b so as to minimize the distance $||M \cdot b - \omega|| = ||\omega' - \omega|| = \delta$.

Further in accordance with a preferred embodiment of the present invention δ is a distance which is minimized such that a sufficiently representative human population perceives the odor r' as an adequate substitute for the odor r.

Still further in accordance with a preferred embodiment of the present invention δ is defined in terms of at least one of the following metrics Euclidean distance, over-threshold Euclidean distance, over-threshold average difference, and maxima distance.

Additionally in accordance with a preferred embodiment of the present invention a normalizing function f is provided which operates on one kind of numerical vectors to form another kind of numerical vectors, not necessarily having the same dimensionality as the first kind

of vectors, with the following property: if ω_1 and ω_2 are outputs of the odor sensor corresponding to odors a_1 and a_2, then the odor a_1 is perceived by a human nose as being close to odor a_2 if and only if $f(\omega_1)$ and $f(\omega_2)$ are numerically close.

In accordance with a preferred embodiment of the present invention the function f is constructed by comparing the sensed odor input vectors ω from a variety of input odors to other vectors produced by collecting data from a human panel for a variety of input odors.

Further in accordance with a preferred embodiment of the present invention the function f is constructed by comparing the sensed odor input vectors ω from a variety of input odors to other vectors produced by collecting data from actual human olfactory receptors.

Still further in accordance with a preferred embodiment of the present invention the function f is constructed by comparing the sensed odor input vectors ω from a variety of input odors to other vectors produced by collecting data from extremely chemically wise simulation of human olfactory receptors.

Additionally in accordance with a preferred embodiment of the present invention there is provided an array of odor-cells, each the odor-cell including an odor encapsulated in an enclosure material, the enclosure material allowing passage of the odor therethrough only upon application of a predetermined level of energy to the enclosure material, and a trigger that selectively applies the predetermined level of energy to the odor-cells. Preferably the trigger applies at least one of heat energy, light energy and mechanical energy.

In accordance with a preferred embodiment of the present invention the trigger includes a scratch implement.

Further in accordance with a preferred embodiment of the present invention the enclosure material has a property of locally rupturing upon application of the predetermined level of energy.

Still further in accordance with a preferred embodiment of the present invention the enclosure material has a permeability which increases upon application of the predetermined level of energy.

Additionally in accordance with a preferred embodiment of the present invention the trigger includes a laser which produces a beam of laser radiation and directs the beam onto the enclosure material.

In accordance with a preferred embodiment of the present invention the odor-cells are mounted on a substrate, and the odor output device further includes a motion device connected to the substrate which moves the substrate with respect to the trigger so as to selectively align one of the odor-cells with the trigger so that the trigger selectively applies the predetermined level of energy to the odor-cells.

Further in accordance with a preferred embodiment of the present invention the odor-cells are mounted on a substrate, and the odor output device further includes a motion device connected to the trigger which moves the trigger with respect to the substrate so as to selectively align one of the odor-cells with the trigger so that the trigger selectively applies the predetermined level of energy to the odor-cells.

Still further in accordance with a preferred embodiment of the present invention there is provided a controller connected to the trigger which controls to which of the odor-cells the trigger selectively applies the predetermined level of energy.

Additionally in accordance with a preferred embodiment of the present invention a fan creates a flow of air over the odor-cells.

In accordance with a preferred embodiment of the present invention the odor sensor includes at least one fragrance sensor which senses a chemical composition of a given odor and communicates odor information including the sensed chemical composition of the given odor to the controller, the controller using the odor information to control to which of the odor-cells the trigger selectively applies the at least one of heat and light energy.

Further in accordance with a preferred embodiment of the present invention the odor sensor includes at least one fragrance sensor which senses a chemical composition of a given odor and communicates odor information including the sensed chemical composition of the given odor to the controller, the controller including a memory device for storing the odor information.

There is also provided in accordance with a preferred embodiment of the present invention an odor output device including an array of odor-cells, each the odor-cell including an odor encapsulated in an enclosure material, the enclosure material allowing passage of the odor therethrough only upon application of a predetermined level of energy to the enclosure material, and a trigger that selectively applies the predetermined level of energy to the odor-cells.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood and appreciated more fully from the following detailed description, taken in conjunction with the drawings in which:

Fig. 1 is a simplified block diagram of an odor transmission system, constructed and operative in accordance with a preferred embodiment of the present invention; and

Fig. 2 is a simplified block diagram of an odor transmission system, constructed and operative in accordance with another preferred embodiment of the present invention, wherein odor vectors are modified by an odor input vector normalizer;

Fig. 3 is a simplified illustration of an odor output device constructed and operative in accordance with a preferred embodiment of the present invention; and

Fig. 4 is a simplified illustration of an alternative trigger for the odor output devices of the present invention, constructed and operative in accordance with a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Reference is now made to Fig. 1 which is a block diagram of an odor transmission system constructed and operative in accordance with a preferred embodiment of the present invention. It is desired to communicate a given input odor r. Odor r may be characterized in a number of ways. For example, gas chromatography can be used to represent odor r as a series of chemical constituents, $c_1, c_2, \ldots c_n$, such as 3 units of H_2S, 5 units of 3-methoxy-4-hydroxybenzaldehyde, and so forth. Alternatively, an artificial nose can be used to represent odor r as a function of "odor characteristics" $s_1, s_2, \ldots s_n$. Similarly, a panel of a representative population of humans can be used to represent odor r as a function of "odor characteristics" $t_1, t_2, \ldots t_n$. In short, odor r can be represented by an odor vector $\omega = (\omega_1, \omega_2, \ldots \omega_n)$ representing any combination of quantifiable factors, such as chemical compounds, pungency, concentration, diffusivity and the like, and qualitative factors such as rose-like, banana-like, etc.

It should be emphasized that it makes no difference to the present invention what the source of odor vector ω is. Odor vector ω can be provided by sensing an object, such as a flower 12, whose odor is not necessarily previously known, as shown in Fig. 1. In the illustrated example, a collector 20 collects and brings the odor r of flower 12 into sensing contact with a sensor 21, such as an artificial nose. Sensor 21 characterizes odor r by the odor vector $\omega = (\omega_1, \omega_2, \ldots \omega_n)$. Alternatively, instead of "smelling" an object, odor vector ω may be artificially created

by a perfumer or movie director, for example, by using an odor-mixing device or a look-up table of a set of known odor vectors, or by polling a panel of human evaluators and adopting the average results, or even by simply using one's imagination to dream up a new odor vector.

An odor output device 27 comprising therein an odorant palette 37 is provided for generating an odor to an end-user via an odor output port 28. Odorant palette 37 can be any kind of odorant mixing device of the art. An essential feature of the present invention is how to instruct odor output device 27 to reproduce odor r as faithfully as possible, which feature is now described.

Odorant palette 37 comprises a plurality of q odorants. In order to use these q odorants as building blocks to reproduce odor r, the q odorants are predefined in terms of the same type of ω vectors used to characterize odor r. In practical terms, this means that the odors given off by the q odorants of palette 37 are pre-sensed by sensor 21 prior to using palette 37 to produce odors. In mathematical terms, odorant palette 37 comprises q odors which are defined by a matrix M of q odor vectors $(\omega_{1,1}, \omega_{1,2}, \ldots \omega_{1,n})$, $(\omega_{2,1}, \omega_{2,2}, \ldots \omega_{2,n})$, ... $(\omega_{q,1}, \omega_{q,2}, \ldots \omega_{q,n})$.

In accordance with the present invention, a concentration vector generator 25 is provided which generates a concentration vector b which instructs palette 37 how to mix the q odorants in order to create an output odor r' which mimics input odor r as closely as possible. The matrix M itself is embodied in concentration vector generator 25 to make possible the following computation: In mathematical terms, matrix M multiplied by concentration vector b creates an odor vector $\omega' = (\omega'_1, \omega'_2, \ldots \omega'_n)$. Concentration vector b is computed so as to minimize the distance $||M \cdot b - \omega|| = ||\omega' - \omega|| = \delta$. In other words, δ is a distance which is minimized such that a sufficiently representative human population perceives odor r' as an adequate substitute for odor r.

The distance δ is defined in terms of some metric. In general, the metric used is the Euclidean distance, i.e., $|| \; ||_2$, in which case a suitable minimization technique is least squares, or calculus of variation. However, δ can also be defined in terms of other metrics, such as the maxima space, i.e., $|| \; ||_\infty$, in which case, techniques of linear programming can be used to minimize the distance δ. Other possible metrics include the over-threshold Euclidean distance and over-threshold average difference. The present invention recognizes the possibility that minimizing the distance in the Euclidean space may be inadequate to mimic odor r. Accordingly, other techniques, such as employing artificial neural networks, are provided in the present invention for

modifying the input vector ω so that a suitable minimization of δ will reflect better how a sufficiently representative human population perceives the output odor r', as described hereinbelow with reference to Fig. 2.

Several important features of the present invention should be noted:

a. If the matrix M is non-singular then $\delta = 0$ can be achieved, and a concentration vector b is calculated to achieve $\delta = 0$, so that the mixture of the q odorants will always produce exactly the odor vector of the input odors. If matrix M is singular then in general $\delta \neq 0$, and the present invention finds a concentration vector that minimizes δ such that a sufficiently representative human population perceives odor r' as an adequate substitute for odor r.

b. The present invention allows defining a set of q primary odorants ("RGB odorants") that can produce a set of m odors within a desired tolerance δ. The present invention recognizes that for many practical applications, one does not need a set of primary odorants that work for every existing odor, but rather for a given set of odors. Nevertheless, it is theoretically possible to use the methods of the present invention to find a universal "RGB" that will be able to reproduce with sufficient accuracy any arbitrary odor.

c. The set of q primary odorants that can produce a set of m odors within a tolerance δ is not necessarily unique. Several sets of q primary odorants may adequately "do the job". The present invention also allows a user to find these sets and optimize and combine them at will.

Reference is now made to Fig. 2 which illustrates an improved version of the system of Fig. 1. In accordance with a preferred embodiment of the present invention, a human nose normalizer 23 is provided which "normalizes" the odor vectors ω produced by sensor 21. By "normalization" it is meant that the odor vectors are modified so that the difference in vector representation between two odor vectors accurately reflects the difference in odor between the two odors which these odor vectors represent.

In mathematical terms, human nose normalizer 23 uses a normalizing function f which operates on one kind of numerical vectors to form numerical vectors of another kind, not necessarily having the same dimensionality as the first kind of vectors, with the following property: if ω_1 and ω_2 are outputs of sensor 21 corresponding to odors a_1 and a_2, then the odor a_1 is perceived by a human nose as being close to odor a_2 if and only if $f(\omega_1)$ and $f(\omega_2)$ are numerically close, e.g., in $\| \; \|_2$.

One way of arriving at normalizing function f is by learning how the differences between ω vectors of sensor 21 actually reflect the differences between the same types of vectors in the "human nose space", such as by a set of vectors π derived from a human panel, as can be understood by the following trivial example. For example, suppose that a particular odor vector ω_1 produced by sensor 21 is composed of the values (17, 5.3, 1.78), each scalar representing a quantity such as chemical concentration, or some dimensionless number related to some odor quantity. The same odor which produced this odor vector ω_1 is then judged by a panel of a sufficiently representative human population which is asked to produce a vector of odor characteristics for that odor. This procedure produces a "human control" vector π_1 with, for example, the values (43.88, 60.84). This example also illustrates that these two vectors do not necessarily have the same length.

Suppose then that another odor is characterized by sensor 21 as the odor vector ω_2 having the values (10.7, 5, 7.3), which when judged by the human control produces vector π_2 with, for example, the values (20, 54). Suppose further that a third odor is characterized by sensor 21 as the odor vector ω_3 having the values (4.35, 4.99, 13.6), which when judged by the human control produces vector π_3 with, for example, the values (19.25, 54.06). Reflecting on these vectors, one notices the apparently illogical fact that while no two of the three ω vectors appear to be close (in the $|| \;||_2$ metric, for example), the two π vectors π_2 and π_3 are extremely close, while π_1 is distant from both of them. In this simple example, one might notice that this could have to do with the proximity of the second components of ω_2 and ω_3 (5 and 4.99) in contrast with the relatively distant 5.3 of ω_1. The purpose of the sought-for function f is to discover these correlations. In this example, an appropriate f would be the function $f(x,y,z) = (y^3-105, 54y-12(x+z))$, that takes the three components of the ω vectors, x, y, and z, and produces the two components of the π vectors. The dominance of y, the second component of the ω vectors, which may possibly represent some critical characteristic of the odors in question, now becomes very clear.

The function f is also used to modify the odorant palette. As mentioned above, odorant palette 37 comprises q odors which are defined by a matrix M of q odor vectors $(\omega_{1,1}, \omega_{1,2}, \ldots \omega_{1,n})$, $(\omega_{2,1}, \omega_{2,2}, \ldots \omega_{2,n})$, ... $(\omega_{q,1}, \omega_{q,2}, \ldots \omega_{q,n})$. The q odor vectors are also operated on by function f, thereby producing a modified matrix, herein referred to as $f(M)$, which is embodied in

concentration vector generator 25 instead of matrix M. The modified vector $f(\omega)$ of the input odor is then input into concentration vector generator 25, as seen in Fig. 2, to provide a better concentration vector b, that is, to minimize the distance $||f(M)\cdot b - f(\omega)||$.

The above is an oversimplified example presented to understand the basic principle of finding and implementing the function f. In actuality, in the case of a human panel, many π odor vectors would be polled by the panel and compared to the ω vectors to arrive at function f. For example, one can choose to represent function f as a polynomial with any number of terms, large or small, depending, *inter alia*, on the "number-crunching" ability of the processors used in the system, and then use best-fit techniques to arrive at the best-fit polynomial. It is of course appreciated by those skilled in the art of mathematics, that other well-known techniques can be used to construct function f, including techniques which handle the case when the dimension of the ω space is not equal to that of the π space.

A second way of arriving at normalizing function f is by learning how differences between ω vectors of sensor 21 are actually sensed by the odor receptors in the human olfactory nerve cells. Such an analysis of real human noses, potentially by remote sensing, including MRI or electromagnetic recordings, would then produce a set of θ vectors, which would be used to construct function f which in turn would be used to create $f(\omega)$ and $f(M)$. $f(M)$ would then be included in concentration vector generator 25 and $f(\omega)$ would be inputted into concentration vector generator 25, as described above.

Alternatively, instead of analysis of real human noses, analysis could be performed on a set of simulated human noses, such as by extremely chemically wise simulation of the θ vector space (i.e., real-life odor receptors in the human olfactory nerve cells). Such an analysis would produce a set of θ_s vectors which could be used to construct function f as described above.

In summary, human nose normalizer 23 provides a normalizing function f that modifies the input vector ω (and the odorant palette vectors) to produce a better concentration vector. The function f can be learned and constructed by comparing the vectors ω from a variety of input odors to other vectors produced in the following ways:

a. Collecting data from a human panel for a variety of input odors.

b. Collecting data from actual human olfactory receptors.

c. Collecting data from extremely chemically wise simulation of human olfactory receptors (artificial neural networks).

By improving the concentration vectors to improve the accuracy of odor duction, or by using a more accurate artificial nose, the relative quality of the q odorants is ved as well. Furthermore, the matrix M (or $f(M)$) associated with the q odorants provides an ation of the ability of the odorants to span all the input odors which are to be reproduced. If atrix is non-singular, then the mixture of the q odorants will always produce exactly the odor or of the input odors and the q odorants thus span all of the input odors.

If matrix M is singular then the q odorants do not span all of the input odors. wn mathematical techniques can be used to calculate to what extent the q odorants span the ut odors in terms of a desired tolerance δ. Moreover, known mathematical techniques can be d to investigate the effects of adding new, additional odorants to the palette, and conversely, e effects of subtracting odorants from the palette. For example, one can calculate if adding rtain odorants to the palette will create a non-singular matrix (and thus span all of the input dors). As another example, one can investigate the behavior of the palette upon the addition of dorants, such as 5 new odorants. If the 5 odorants greatly increase the span of the odorant alette, then they may be considered for expanded use of the palette. Conversely, if by subtracting odorants from the palette no significant degradation in the ability of the palette to span the input dors is detected, then one can save costs by minimizing the number of odorants in the palette. In short, by using known mathematical techniques, matrix M and function f permit initially defining a set of q primary odorants ("RGB odorants") that can produce a set of input odors within a tolerance δ, as well as modifying and optimizing the set of q odorants.

Reference is now made to Fig. 3 which illustrates an odor output device 110 constructed and operative in accordance with a preferred embodiment of the present invention, which employs the q primary odorants mentioned above.

Odor output device 110 preferably includes an array of odor-cells 112 mounted on a (preferably solid) substrate 114. Each odor-cell 112 includes an odorant 116 encapsulated in an enclosure material 118. Odorants 116 are preferably the q primary odorants. Odorants 116 may be chosen in a number of ways. For example, it may be desired to use odor output device 110 to approximate a plurality of input odors, such as perfumes, that include perfumes with known odors plus some with unknown odors. An initial plurality of odorants 116 may be selected that have a reasonable expectation of approximating at least the known odors. Then, as mentioned hereinabove, known mathematical techniques can be used to calculate to what extent the initially

chosen odorants 116 span the input odors in terms of a desired tolerance δ. Moreover, known mathematical techniques can be used to investigate the effects of adding new, additional odorants to the palette, and conversely, the effects of subtracting odorants from the palette of odor output device 110.

A trigger 120, comprising different embodiments as described further hereinbelow, is in operative communication with odor-cells 112. Enclosure material 118 permits passage of encapsulated odorant 116 into a surrounding environment only when trigger 120 creates an opening in enclosure material 118 sufficient for passage therethrough of odorant 116.

The type of trigger employed depends, *inter alia*, on the type of encapsulation. Odorant 116 may be encapsulated in one of three manners:

a. Microcapsule (reservoir)

b. Polymer matrix

c. Microencapsulated dispersed odor-polymer

In Fig. 3, odor-cells 112 are preferably constructed of layers of a polymer matrix that may contain between 50-1000 different kinds of odorants. In order to understand the amount of odor substance contained in the polymer matrix, several terms are first defined. "Odor signal" is defined as a portion of air carrying fragrance in a concentration sufficient for smell by humans. For many types of odorants, an ordinary person needs between 10 ngr - 10 μg of fragrance material in 1 liter air in order to feel an "odor signal". These small amounts enable constructing substrate 114 with thousands of potential breaths of each fragrance in a relatively compact size. Alternatively, odor-cells 112 can be constructed as microcapsules attached to substrate 114. Substrate 114 can be fashioned in any arbitrary shape, such as like a compact disc (CD).

In one preferred embodiment of the present invention, trigger 120 comprises a laser 122 which produces a beam 124 of laser radiation and directs beam 124 onto enclosure material 118. Enclosure material 118 is preferably a light absorbing polymer with high absorptivity in the laser wavelength. The high absorptivity is preferably due to the addition of dye to the polymer, with strong absorption at the laser wavelength, or due to the use of polymer that is intrinsically absorbing at the exposure wavelength. Laser beam 124 may be continuous or pulsed. The laser beam wavelength may be arbitrary, but is most preferably between 680-1500 nm. The pulse intensity and duration of laser beam 124 control the amount of odor 116 released from odor-cell

112. The laser apparatus can include optical fibers, lenses and other devices to focus and shape laser beam 124.

Laser beam 124 of trigger 120 creates an opening in enclosure material 118 sufficient for passage therethrough of odor 116. Laser beam 124 can release odor 116 in one of three methods:

a. Evaporation of odor 116 that causes local explosion/rupture of the polymer wall of enclosure material 118

b. Evaporation or destruction of the polymer wall of enclosure material 118 causing odor 116 to escape outwards

c. Increase of the polymer wall permeability, causing faster diffusion of odor 116.

In accordance with one embodiment of the present invention, enclosure material 118 is also a heat-sensitive polymer, so that absorption of beam 124 heats the enclosure material to a temperature which causes changes in the enclosure material, in accordance with any of the three methods listed above in subparagraphs a, b and c. Examples of heat sensitive microcapsules are described in Japanese Patent Document 02145383 to Wakata and EP Patent 38985 to Bayer, in which a volatile material is released from a core of a capsule due to temperature changes in the enclosure. Another type of heat-release capsule is used in the food industry, for example, microencapsulated flavors such as Ottens Flavors MagnaCap™ are designed for release during baking at 145°F (63°C). Other examples of heat sensitive materials for such microcapsules are described in US Patent 4,742,043 to Tanaka et al., US Patent 4,760,048 to Kurihara et al., the disclosures of which are incorporated herein by reference.

It is noted that the enclosure polymer should preferably have a low thermal conductivity to prevent heat produced by laser beam 124 from traveling by conduction to other areas in the polymer. This ensures the required localized heating of the particular odor-cell 112.

Alternatively, the heat energy required to heat enclosure material 118 may be provided by an electric device, such as a precise thermal head that has a high resolution allowing it to heat small areas. A thermal head suitable for this purpose is a thermal printing head, such as that described in US Patent 4,559,542 to Mita, the disclosure of which is incorporated herein by reference.

Substrate 114 may include layers of encapsulated odors apportioned into sections, each section including different odor. Odor output device 110 preferably includes a motion device

130 connected to substrate 114 which moves substrate 114, together with odor-cells 112, with respect to trigger 120 so as to selectively align one of odor-cells 112 with laser beam 124 of trigger 120. In this manner, trigger 120 can selectively cause any combination of odor-cells 112 to release the particular odor of odorant 116.

In one embodiment, motion device 130 is preferably a motor which rotates substrate 114 about a spindle axis 132. Trigger 120 is moved generally radially with respect to axis 132 by another motion device 134. Substrate 114 is rotated by motion device 130 until the desired fragrance location is below laser beam 124. This system is thus similar to the system in a CD player or magnetic disk memory device.

Alternatively, trigger 120 may remain stationary while substrate 114 is moved by motion device 130 in Cartesian or other coordinates in a plane generally perpendicular to axis 132.

Preferably a fresh air pipe 136 is provided for introducing fresh, clean air above the substrate 114 and odor-cells 112. An exhaust pipe 138 is preferably positioned at a mixing region (or mixing chamber) 140 above the substrate 114 and odor-cells 112 to deliver the air with the odors to a user's nose. The position of pipes 136 and 138 can be either horizontal or vertical relative to substrate 114, and the pipes may even be concentric.

In summary, odor output device 110 creates a composite odor from a combination of basic odors in different intensities. Trigger 120 and substrate 114 move relative to each other so as to release the precise amount of odor to the mixing region 140, just above substrate 114. The mixture of odors in the mixing region is delivered to the user's nose. After each fragrance emission, a flow of fresh air through pipes 136 and 138 cleans and clears apparatus 110.

Odor output device 110 may also include a controller 142 connected to trigger 120 which controls which odor-cells 112 are triggered by trigger 120 to release odors 116. Additionally, the system of odor output device 110 preferably includes one or more fragrance sensors 144 which sense a chemical composition of a given odor and communicate odor information comprising the sensed chemical composition of the given odor to controller 142, either by wired or wireless transmission. Controller 142 uses the odor information to control which odor-cells 112 are triggered by trigger 120 to release odors 116. Additionally or alternatively, controller 142 includes a memory device 146 for storing the odor information.

Reference is now made to Fig. 4 which illustrates an alternative trigger for the odor output devices of the present invention. Here the trigger comprises a scratch implement 180 which

can scratch and rupture enclosure material 118 of odor-cell 112, thereby releasing odorant 116. Thus the trigger of the odor output devices of the present invention can use heat energy, light energy or mechanical energy to trigger emission of odors from odor-cells 112.

It will be appreciated by persons skilled in the art that the present invention is not limited by what has been particularly shown and described hereinabove. Rather the scope of the present invention includes both combinations and subcombinations of the features described hereinabove as well as modifications and variations thereof which would occur to a person of skill in the art upon reading the foregoing description and which are not in the prior art.

CLAIMS

What is claimed is:

1. An odorant concentration system comprising:

an odor vector generator providing an odor vector representing an arbitrary odor;

an odorant concentration vector generator receiving said odor vector and producing an odorant concentration vector.

2. A system for reproducing odors comprising:

an odor sensor providing a sensed odor input vector representing an arbitrary odor sensed thereby;

an odor output device, having a palette containing a multiplicity of predetermined odorants each having a predetermined odor signature, said odor output device providing a composite odor in response to an odorant concentration vector; and

an odorant concentration vector generator receiving said sensed odor input vector and utilizing said predetermined odor signatures to produce said odorant concentration vector.

3. The system for reproducing odors according to claim 2 and wherein said odorant concentration vector generator comprises a sensed odor input vector normalizer which modifies the sensed odor input vector such that the output of the sensor is normalized, whereby odors which are similar as perceived by a human are represented by modified odor input vectors which are close.

4. The system for reproducing odors according to claim 3 and wherein said odorant concentration vector generator normalizes said predetermined odor signatures to the output of the human nose.

5. The system for reproducing odors according to claim 3 and wherein said modified odor input vectors which are close, are close according to at least one of the following metrics: Euclidean distance, over-threshold Euclidean distance, over-threshold average difference, and maxima distance.

6. The system for reproducing odors according to claim 2 and wherein said odorants of said palette are predefined in terms of a plurality of sensed odor input vectors, wherein said palette comprises q odorants which are defined by a matrix M of q odor vectors $(\omega_{1,1}, \omega_{1,2}, \ldots \omega_{1,n})$, $(\omega_{2,1}, \omega_{2,2}, \ldots \omega_{2,n})$, ... $(\omega_{q,1}, \omega_{q,2}, \ldots \omega_{q,n})$.

7. The system for reproducing odors according to claim 6 and wherein said concentration vector generator generates a concentration vector b which instructs said palette how to mix the q odorants in order to create an output odor r' which mimics an input odor r, wherein the matrix M multiplied by the concentration vector b creates an odor vector $\omega' = (\omega'_1, \omega'_2, \ldots \omega'_n)$ and said concentration vector generator chooses the concentration vector b so as to minimize the distance $||M{\cdot}b - \omega|| = ||\omega' - \omega|| = \delta$.

8. The system for reproducing odors according to claim 7 and wherein δ is a distance which is minimized such that a sufficiently representative human population perceives the odor r' as an adequate substitute for the odor r.

9. The system for reproducing odors according to claim 8 and wherein δ is defined in terms of at least one of the following metrics: Euclidean distance, over-threshold Euclidean distance, over-threshold average difference, and maxima distance.

10. The system for reproducing odors according to claim 3 and comprising a normalizing function f which operates on one kind of numerical vectors to form another kind of numerical vectors, not necessarily having the same dimensionality as the first kind of vectors, with the following property: if ω_1 and ω_2 are outputs of said odor sensor corresponding to odors a_1 and a_2, then the odor a_1 is perceived by a human nose as being close to odor a_2 if and only if $f(\omega_1)$ and $f(\omega_2)$ are numerically close.

11. The system for reproducing odors according to claim 10 and wherein said function f is constructed by comparing the sensed odor input vectors ω from a variety of input odors to other vectors produced by collecting data from a human panel for a variety of input odors.

12. The system for reproducing odors according to claim 10 and wherein said function f is constructed by comparing the sensed odor input vectors ω from a variety of input odors to other vectors produced by collecting data from actual human olfactory receptors.

13. The system for reproducing odors according to claim 10 and wherein said function f is constructed by comparing the sensed odor input vectors ω from a variety of input odors to other vectors produced by collecting data from extremely chemically wise simulation of human olfactory receptors.

14. The system according to claim 2 and wherein said odor output device comprises:

an array of odor-cells, each said odor-cell comprising an odor encapsulated in an enclosure material, said enclosure material allowing passage of the odor therethrough only upon application of a predetermined level of energy to said enclosure material; and

a trigger that selectively applies said predetermined level of energy to said odor-cells.

15. The system according to claim 14 and wherein said trigger applies at least one of heat energy, light energy and mechanical energy.

16. The system according to claim 14 and wherein said trigger comprises a scratch implement.

17. The system according to claim 14 and wherein said enclosure material has a property of locally rupturing upon application of said predetermined level of energy.

18. The system according to claim 14 and wherein said enclosure material has a permeability which increases upon application of said predetermined level of energy.

19. The system according to claim 14 and wherein said trigger comprises a laser which produces a beam of laser radiation and directs said beam onto the enclosure material.

20. The system according to claim 14 and wherein said odor-cells are mounted on a substrate, and said odor output device further comprises a motion device connected to said substrate which moves said substrate with respect to said trigger so as to selectively align one of said odor-cells with said trigger so that said trigger selectively applies said predetermined level of energy to said odor-cells.

21. The system according to claim 14 and wherein said odor-cells are mounted on a substrate, and said odor output device further comprises a motion device connected to said trigger which moves said trigger with respect to said substrate so as to selectively align one of said odor-cells with said trigger so that said trigger selectively applies said predetermined level of energy to said odor-cells.

22. The system according to claim 14 and comprising a controller connected to said trigger which controls to which of said odor-cells said trigger selectively applies said predetermined level of energy.

23. The system according to claim 14 and comprising a fan which creates a flow of air over said odor-cells.

24. The system according to claim 22 and wherein said odor sensor comprises at least one fragrance sensor which senses a chemical composition of a given odor and communicates odor information comprising the sensed chemical composition of the given odor to said controller, said controller using the odor information to control to which of said odor-cells said trigger selectively applies said at least one of heat and light energy.

25. The system according to claim 22 and wherein said odor sensor comprises at least one fragrance sensor which senses a chemical composition of a given odor and communicates odor information comprising the sensed chemical composition of the given odor to said controller, said controller comprising a memory device for storing the odor information.

26. An odor output device comprising:

an array of odor-cells, each said odor-cell comprising an odor encapsulated in an enclosure material, said enclosure material allowing passage of the odor therethrough only upon application of a predetermined level of energy to said enclosure material; and

a trigger that selectively applies said predetermined level of energy to said odor-cells.

27. The odor output device according to claim 26 and wherein said trigger applies at least one of heat energy, light energy and mechanical energy.

28. The odor output device according to claim 26 and wherein said trigger comprises a scratch implement.

29. The odor output device according to claim 26 and wherein said enclosure material has a property of locally rupturing upon application of said predetermined level of energy.

30. The odor output device according to claim 26 and wherein said enclosure material has a permeability which increases upon application of said predetermined level of energy.

31. The odor output device according to claim 26 and wherein said trigger comprises a laser which produces a beam of laser radiation and directs said beam onto the enclosure material.

32. The odor output device according to claim 26 and wherein said odor-cells are mounted on a substrate, and said odor output device further comprises a motion device connected to said substrate which moves said substrate with respect to said trigger so as to selectively align one of said odor-cells with said trigger so that said trigger selectively applies said predetermined level of energy to said odor-cells.

33. The odor output device according to claim 26 and wherein said odor-cells are mounted on a substrate, and said odor output device further comprises a motion device connected to said trigger which moves said trigger with respect to said substrate so as to selectively align one of said odor-cells with said trigger so that said trigger selectively applies said predetermined level of energy to said odor-cells.

34. The odor output device according to claim 26 and comprising a controller connected to said trigger which controls to which of said odor-cells said trigger selectively applies said predetermined level of energy.

35. The odor output device according to claim 26 and comprising a fan which creates a flow of air over said odor-cells.

36. The odor output device according to claim 34 and comprising at least one fragrance sensor which senses a chemical composition of a given odor and communicates odor information comprising the sensed chemical composition of the given odor to said controller, said controller using the odor information to control to which of said odor-cells said trigger selectively applies said at least one of heat and light energy.

37. The odor output device according to claim 34 and comprising at least one fragrance sensor which senses a chemical composition of a given odor and communicates odor information comprising the sensed chemical composition of the given odor to said controller, said controller comprising a memory device for storing the odor information.

38. A method for reproducing odors comprising:

providing an odor input vector representing an arbitrary odor;

providing an odor output device, having a palette containing a multiplicity of predetermined odorants each having a predetermined odor signature, said odor output device providing a composite odor in response to an odorant concentration vector; and

inputting said odor input vector into an odorant concentration vector generator which utilizes said predetermined odor signatures to produce said odorant concentration vector.

39. The method according to claim 38 and comprising predefining said odorants of said palette in terms of a plurality of odor input vectors, wherein said palette comprises q odorants which are defined by a matrix M of q odor vectors $(\omega_{1,1}, \omega_{1,2}, \ldots \omega_{1,n})$, $(\omega_{2,1}, \omega_{2,2}, \ldots \omega_{2,n})$, ... $(\omega_{q,1}, \omega_{q,2}, \ldots \omega_{q,n})$.

40. The method according to claim 39 and comprising generating a concentration vector b which instructs said palette how to mix the q odorants in order to create an output odor r' which mimics an input odor r, wherein the matrix M multiplied by the concentration vector b creates an odor vector $\omega' = (\omega'_1, \omega'_2, \dots \omega'_n)$ and the concentration vector b is chosen so as to minimize the distance $||M \cdot b - \omega|| = ||\omega' - \omega|| = \delta$.

41. The method according to claim 40 and comprising calculating to what extent the q odorants span the input odors in terms of δ.

42. The method according to claim 41 and comprising investigating effects of adding new, additional odorants to the palette by investigating changes caused thereby in minimization of δ.

43. The method according to claim 41 and comprising investigating effects of subtracting odorants from the palette by investigating changes caused thereby in minimization of δ.

44. The system according to any of claims 1-25 and substantially as described hereinabove.

45. The output odor device according to any of claims 26-37 and substantially as described hereinabove.

For the Applicant,

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Advocates & Patent Attorneys
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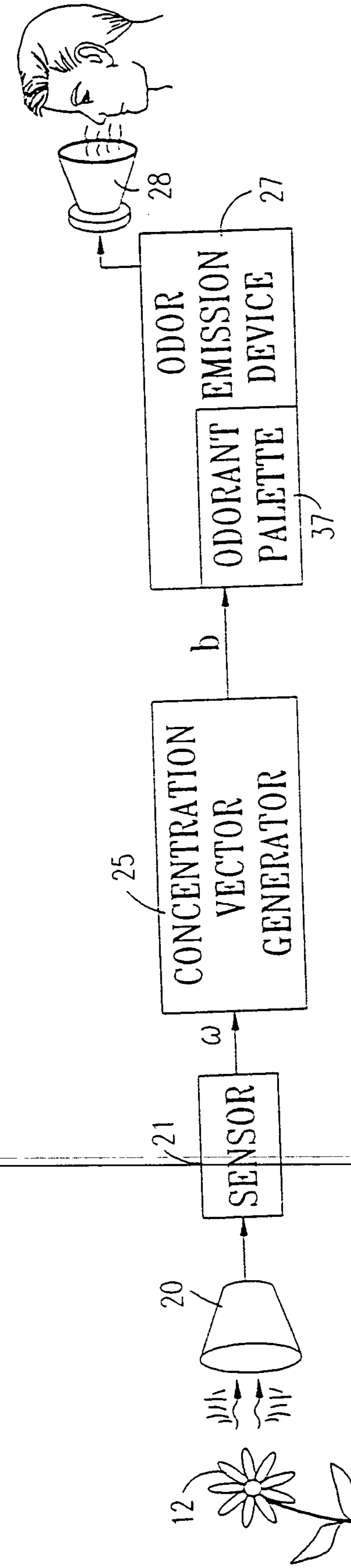
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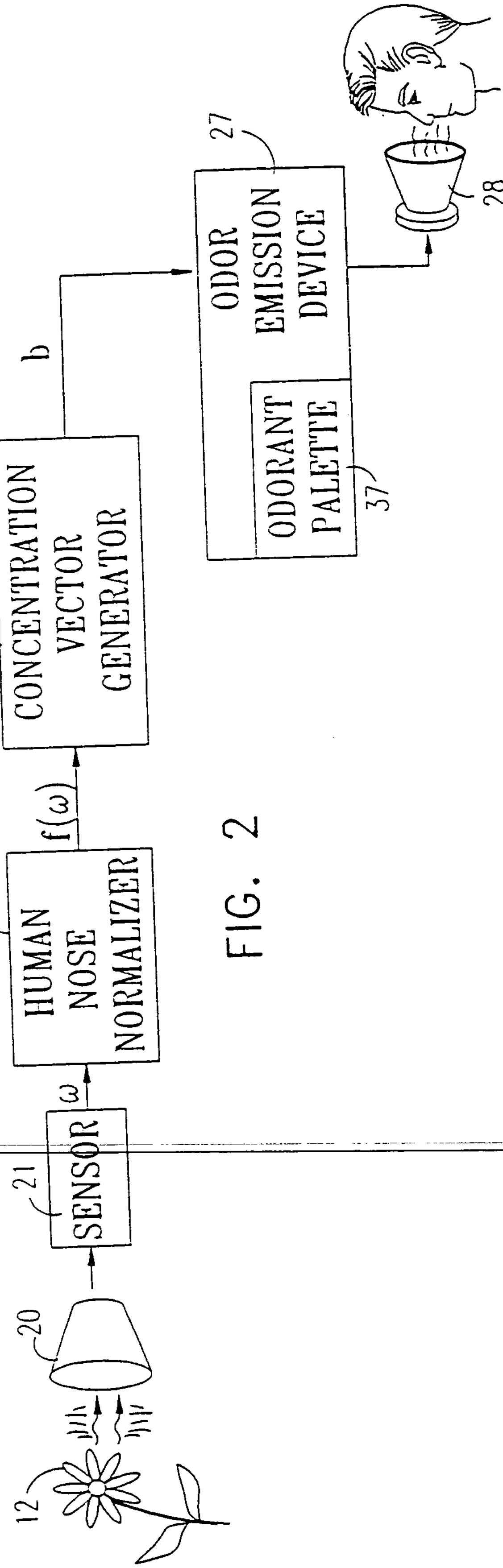
20
21
SENSOR
ω
25
CONCENTRATION
VECTOR
GENERATOR
b
ODORANT
PALETTE
37
ODOR
EMISSION
DEVICE
27
28

FIG. 1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ODOR
EMISSION
DEVICE
27
28

FIG. 2

FIG. 3

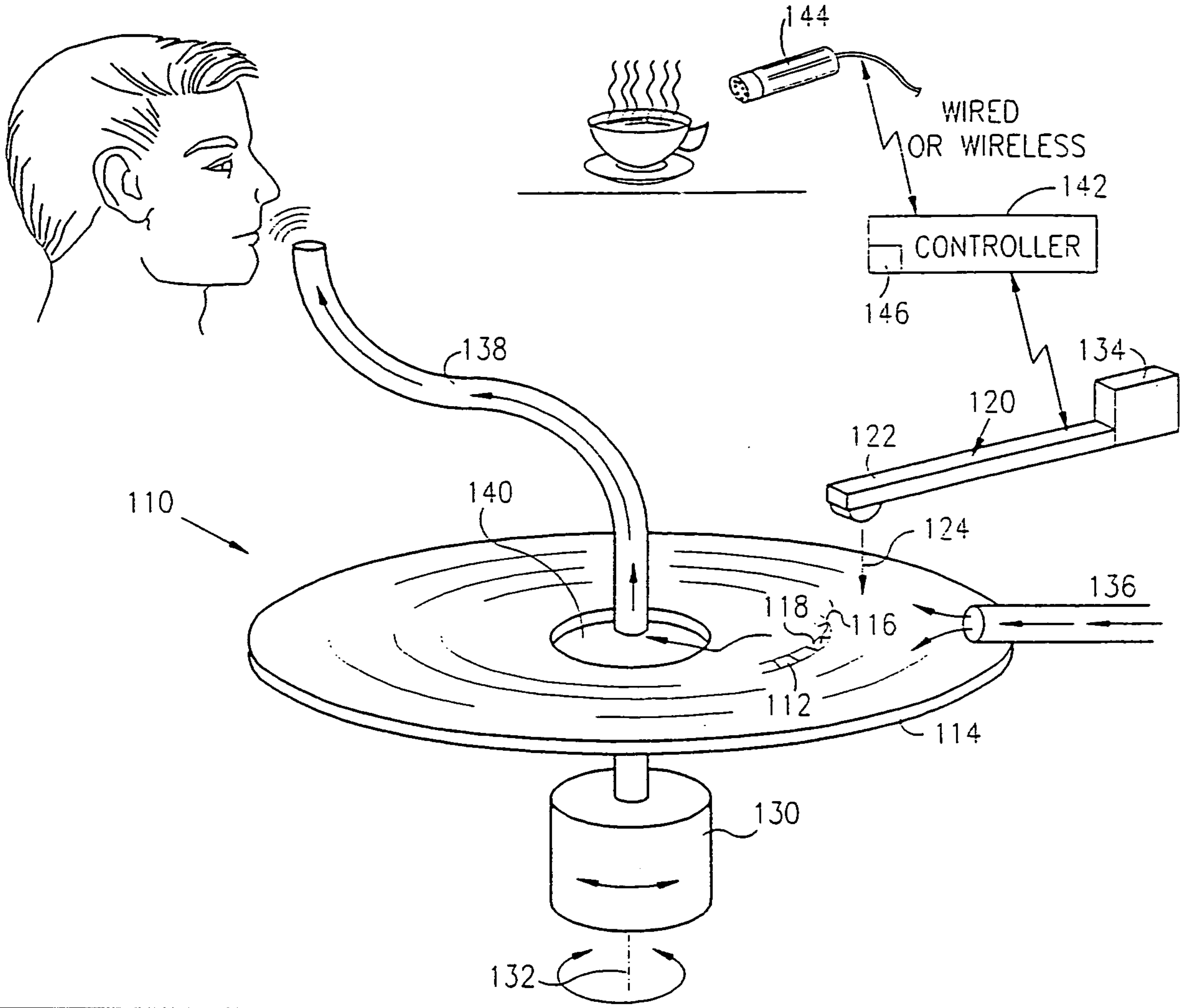
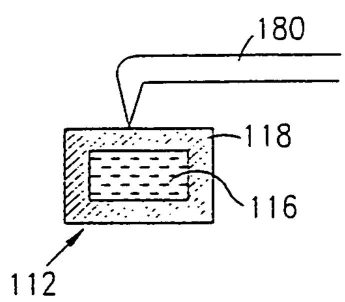

144
WIRED
OR WIRELESS
142
CONTROLLER
146
138
134
120
122
110
140
124
136
118
116
112
114
130
132

FIG. 4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